

## A Review of Methods Used for Purification of Biogas

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### Abstract

Biogas produced from the fermentation process of methane contains 59-71% methane with some other components such as water, small quantities of oxygen and nitrogen, hydrogen sulphide, carbon dioxide, and water vapors. Due to these ingredients, the heating value and efficiency of biogas reduces and can also cause corrosion of instruments if used as fuel. Also, gases like CO<sub>2</sub> and H<sub>2</sub>S have a very pungent smell and are toxic in nature thus making the food toxic and low quality. These are the reasons why we need to purify biogas. Biogas purification involves removal of CO<sub>2</sub> and H<sub>2</sub>S, the toxic gases. The methods we use for purification of biogas involve physical methods, chemical methods, and biological methods. Purified biogas i.e. biomethane is a promising renewable energy which will help in increasing food quality as well as reduce pollution. Purified biogas is a very cost-effective as well as a very good alternative to natural gas.

**Keywords:** biogas, biogas purification, chemical absorption, membrane technology, carbon capture.

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### 1. Introduction

Anaerobic digestion of organic matter including animal waste, food scraps, plant material, wastes from agricultural products, household wastes, industrial waste, and energy crops produces a renewable fuel which is called biogas [1]. At both domestic and commercial levels, biogas is used as a fuel for cooking food, producing power, and producing heat. Biogas contains 59-71% methane with some other components such as water, small quantities of oxygen and nitrogen, hydrogen sulphide, carbon dioxide, and water vapors. Due to these ingredients, the heating value and efficiency of biogas reduces and can also cause corrosion of instruments if used as fuel. Presence of these gases especially CO<sub>2</sub> and H<sub>2</sub>S have a very pungent smell and are very toxic in nature thus making the food toxic and reducing food quality. Because of the presence of these component gases in the biogas, biogas need purification before we can use biogas as a source of energy. Treatment of biogas removes its toxicity, increases heating value of biogas, removes any pungent and unwanted smell, and reduces pollution caused by used of biogas. CO<sub>2</sub> can cause suffocation and death while H<sub>2</sub>S when combined with water forms sulphuric acid which is a highly toxic and corrosive material. These are reasons why we need easy, safe & cost-effective methods for purification of biogas.

Biogas is quite different from natural gas and the difference between the two gases lies between its CO<sub>2</sub> content. The composition of biogas can also differ on the basis of their origin [2]. These component gases are the key to toxicity and pollution caused by biogas in comparison to

natural gas. Both of these gases have different compositions of the component gases and the variation in the composition of biogas originates because the source of its production. This difference in the composition of both gases can be seen in the table 1. Biogas mainly consists of CH<sub>4</sub> and CO<sub>2</sub> [3]. Biogas is delivered to a wide number of markets and applications, including power, heat, and transportation fuels [4]. The most popular, simple, and easiest way of obtaining energy from biogas is combustion of biogas. Although biogas is a source of the renewable energy at domestic as well as industrial level, it is not easy and safe to use biogas as raw gas. Gases like CO<sub>2</sub> and H<sub>2</sub>S present in biogas cause food toxicity, reducing food quality, and health issues at domestic level and corrosion of instruments, pollution, and H<sub>2</sub>SO<sub>4</sub> production at industrial level. These are the reasons why biogas needs purification before using.

### 2. Methods of purification

The methods used for biogas purification involve physical, chemical, and biological methods (Figure 1).

#### 2.1. Physical methods

Physical methods are very efficient in removing CO<sub>2</sub> and H<sub>2</sub>S but in order to do so these require a large amount of water. Also, it requires high temperature, pressured water, water recirculation, and treatment of wastewater. It also requires electrical energy for water sprinkling and purification. Majority of the studies in the field of physical treatments focus on laboratory-scale water purification

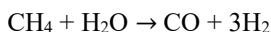
systems. In a sophisticated industrial process, a specialized apparatus is required due to the large quantity of water being used and a treatment plant for the purification of wastewater producing in this process.

### 2.1.1. Removal of CO<sub>2</sub>

Water is a universal solvent and it has the ability to dissolve CO<sub>2</sub> [5]. CO<sub>2</sub> dissolves in water and forms carbonic acid [6].



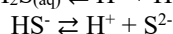
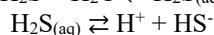
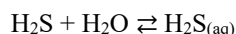
Methane and water generate carbon monoxide which can cause reduction in heating value and efficiency and can increase toxicity.



In the pressurized water purification method, biogas is fed from the bottom in to a packed bed column, and pressurized water is sprayed from the top of the column, the biogas purification is a counter-current process. In this way, the CO<sub>2</sub> is dissolved in the water and exits through the bottom of the tower, allowing an efficiency of process to increase with 95% CO<sub>2</sub> removed (Figure 2) [7]. According to the studies, purification of biogas depends on the water flow rate, pressure in the scrubbing column, and the biogas flow rate in the tower. The table 2 shows a comparison between different methods of physical absorption of CO<sub>2</sub>.

### 2.1.2. Removal of H<sub>2</sub>S

At 20°C, H<sub>2</sub>S dissolves in water at a rate of 0.41 g per 100ml and yields sulphur and hydronium ions [6]. The solubility of H<sub>2</sub>S is influenced by temperature in a direct relation.



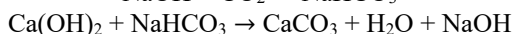
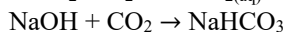
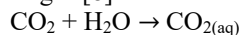
Removal of H<sub>2</sub>S was measured in a series of reaction with different levels of water and result of the experiments is given in the table 3.

## 2.2. Chemical methods

In order to maximize its utilization and increase process efficiency, it is crucial to research different conditions. The use of organic materials in form of activated carbon has been a novel material for purification of biogas.

### 2.2.1. Removal of CO<sub>2</sub>

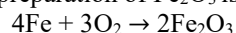
In chemical methods, strong bases including calcium hydroxide (Ca(OH)<sub>2</sub>), sodium hydroxide (NaOH), and potassium hydroxide (KOH) have been used to remove CO<sub>2</sub> and H<sub>2</sub>S from biogas [8].



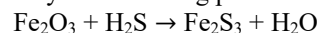
The removal of CO<sub>2</sub> in different reagents was checked and the results are discussed in the table 4. CO<sub>2</sub> can be removed chemically using a variety of chemical reagents but the drawback to this method is that these chemicals can be expensive, hard to find, and not easy to implement on the large scale industries [6]. It is important to know that the bases used in this process must be strong diluted bases.

### 2.2.2. Removal of H<sub>2</sub>S

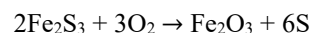
For the removal of H<sub>2</sub>S from biogas, iron oxide (Fe<sub>2</sub>O<sub>3</sub>) is used. Iron oxide is easy to make and can efficiently separate H<sub>2</sub>S. The preparation of Fe<sub>2</sub>O<sub>3</sub> is given as below:



The process of removal of H<sub>2</sub>S from biogas by using Fe<sub>2</sub>O<sub>3</sub> takes place by the following process:



Fe<sub>2</sub>O<sub>3</sub> can be easily regenerated from Fe<sub>2</sub>S<sub>3</sub> by reacting it with oxygen.



The removal of H<sub>2</sub>S in different reagents was checked and the results are discussed in the table 5 [6].

## 2.3. Biological methods

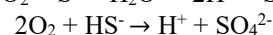
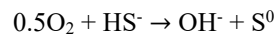
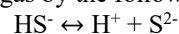
For the purification of biogas, biological techniques are both cost-effective and fascinating. Chemotrophic or photosynthetic bacteria are the primary focuses of research in this area. Biological methods of biogas purification are ecologically friendly, cost-effective, require no chemical products, use little energy, have high rates of degradation, and are supported by biofilms. However, biological processes are inefficient and easily contaminated by isolated microbes [9].

### 2.3.1. Removal of CO<sub>2</sub>

The experimental process for the removal of CO<sub>2</sub> biologically was carried out using the photoautotrophic microalgae (*Chlorella vulgaris*), the results show that yield of 91% CH<sub>4</sub> is obtained (Figure 3). This process was carried out using different species and the results discovered are shown in the table 6 [6].

### 2.3.2. Removal of H<sub>2</sub>S

For removal of H<sub>2</sub>S biological methods have been studied but on the laboratory scale. Microorganisms can remove H<sub>2</sub>S from biogas by the following pathway:



There is a variety of microbes which can remove H<sub>2</sub>S from biogas which are given in the table 7 [6].

## 3. Recent Advances in Biogas Purification Technologies

The techniques studied in order to accelerate biogas disintegration have been widely studied which include heat-induced steam explosion of waste material for intracellular biomass disintegration [10], sonification [11], and water plasma expansion using phytomass disintegration [1-12]. The recent work done in this field focuses on removal of CO<sub>2</sub> and H<sub>2</sub>O more efficiently (Figure 4).

### 3.1. Pressure Swing Adsorption (PSA)

Adsorption system contains a solute which transfers with the stream of gas working as an adsorbent [3]. In PSA different gases like CO<sub>2</sub>, N<sub>2</sub>, and O<sub>2</sub> are separated at different pressures by using either activated carbon or zeolites [13]. Adsorption of the gases in PSA is a reversible process. H<sub>2</sub>S can also be adsorbed in this process, but the process is irreversible, making it unfavorable for H<sub>2</sub>S [6]. In order to protect the adsorbent material, H<sub>2</sub>S is separated individually [14]. The yield of biomethane obtained using this technique ranges from 90% to 99% by different authors. This technique is very useful because it requires low energy consumption, no chemical is required, and it is compact, thus it is very common in low-scale industries. The drawbacks of this technique are that it is less efficient than other techniques and

it requires treatment to remove H<sub>2</sub>S and water before the process starts (Figure 5).

### 3.2. Absorption

The purification of biogas by the process of absorption requires liquid scrubbing so that CO<sub>2</sub> is absorbed using either chemical or physical processes [15].

#### 3.2.1. High pressure water scrubbing (HPWS)

For this process it is required to know the solubility of all the ingredients of biogas because the principle of HPWS lies in the fact that CO<sub>2</sub> and H<sub>2</sub>S have high solubility in H<sub>2</sub>O, which is used as an absorbent, as compared to other components [16]. HPWS is carried out using packed columns with optimized conditions in order to achieve the highest emission of CO<sub>2</sub> [17]. Biomethane produced from this technique ranges between 95%-97%. This technique is easy to use, cheap, and able to remove NH<sub>3</sub> and H<sub>2</sub>S from biogas. It requires low electricity consumption and is flexible in capacity, thus it is the most applied technique in industries. The drawbacks to this technique are that CH<sub>4</sub> obtained is of medium-high composition, losses of CH<sub>4</sub> are about 2%, is not very flexible in terms of composition of biogas, and a drying stage is required after scrubbing (Figure 6).

#### 3.2.2. Organic physical scrubbing (OPS)

OPS is quite identical to that of water scrubbing except that the solvent used in it as an absorbent. In this technique an organic solvent like polyethylene glycol is used instead of water [18-19]. Solubility of CO<sub>2</sub> is higher in polyethylene glycol than in water, thus we require less adsorbent and a smaller equipment in OPS than HPWS [6]. Both techniques give almost the same yield [20]. Polyethylene glycol used in this process can be regenerated along with H<sub>2</sub>O, H<sub>2</sub>S, and O<sub>2</sub> [6]. On a commercial level, other adsorbents like selexol and genosorb are used [15-21]. CO<sub>2</sub> and NH<sub>3</sub> are more soluble in selexol than in H<sub>2</sub>O, also selexol has low freezing point and is noncorrosive in nature [6]. Selexol has the ability to dissolve H<sub>2</sub>S in higher quantities than CO<sub>2</sub> and for regeneration of H<sub>2</sub>O and H<sub>2</sub>S from selexol high temperature is required [6]. Low losses of CH<sub>4</sub> are faced in this technique than HPWS. It is also able to eliminate H<sub>2</sub>S, ammonia, and other impurities, but a pre-treatment is required. Yield obtained from OPS is similar to that of HPWS i.e. CH<sub>4</sub> obtained is of medium-high composition, requires high investment for operation, and is difficult to operate because this technique requires high temperature for a complete regeneration of gases (Figure 7).

#### 3.2.3. Chemical scrubbing

Chemical scrubbing involves chemical reaction between the absorbent and the absorbed gases [6]. The absorbent used in this technique is mostly an amine for the removal of CO<sub>2</sub> or H<sub>2</sub>S either in the form of Monoethanolamine (MEA), Diethanolamine (DEA), or Methyldiethanolamine (MDEA) [6]. Chemical reactions occurring with amine in chemical scrubbing are highly selective in order to keep the losses below 0.1% and purity of biomethane above 99.9% [15-21]. Optimized conditions required for chemical scrubbing are 120°C and 1-2 bar pressure [22-23]. The amine solution is also lost in this technique due to evaporation [14]. The regeneration of gases occurs at high temperature and requires high energy

consumption [15]. This technique gives the highest purity of biomethane (>99%) and low losses are obtained are very minimum (<0.1%). There are no pressurization of biogas and High CO<sub>2</sub> elimination takes place. The drawbacks to this technique are that it requires a high investment cost, high temperature for regeneration of gases, causes corrosion and salt precipitation. In this technique, foam is produced and removal of H<sub>2</sub>S requires pre-treatment (Figure 8).

### 3.3. Membrane separation

In membrane separation technique, membranes which are permeable to CO<sub>2</sub>, H<sub>2</sub>O, and NH<sub>3</sub> are used for the purification of biogas [6]. H<sub>2</sub>S and O<sub>2</sub> also pass through the membrane. CH<sub>4</sub> passes through the membrane in a very low proportion and this makes the separation of gases possible [15]. The purification of biogas by membrane separation can take place by either wet process or dry process [6]. This technique can be simply constructed, the operation requires a little maintenance, and has modular configuration. This technique requires no heating and no chemical products. It is highly reliable and smaller gas flows can be treated without any greater cost increase. The drawbacks of this technique are that membrane has low, several stages are required to achieve high purity of biomethane, medium to high losses of CH<sub>4</sub>. This technique is not suitable for biogas with undetermined pollutants, such as landfill gas or wastewater biogas. This technique has a high cost because of membranes and is not widespread in industries (Figure 9).

### 3.4. Cryogenic separation

The cryogenic separation technique is based on the difference in boiling point of different components for the purpose of purification of biogas. In this technique biogas is compressed at a low temperature so that CO<sub>2</sub> condenses and can be separated as liquid [6]. By this technique, high purity biomethane is produced, causes low methane losses (<1%), pure CO<sub>2</sub> is obtained as a byproduct, and no chemicals are required. The drawbacks of this technique are that it requires a high cost for operation, requires pre-treatment to eliminate contaminants, efficiency is low, and technology is not very demonstrated. This technique is very recently implemented on large-scale industries (Figure 10).

## 4. Future Perspectives

In all the methods we have studied so far, the purification process mainly focuses on removal of CO<sub>2</sub> and H<sub>2</sub>S. It is important that when a new study is carried out for purification of biogas, the substrate considered for use must be of low cost, environment-friendly, and safe to use. The process of biogas upgradation is intended to generate a sustainable and profitable process with zero waste. These considerations in the process will allow the user to produce biogas simply with the available material at a low cost. Use of biomethane helps in reducing waste, pollution, toxicity, and greenhouse gases, thus it is important to continue studies in this field. Since the yield of biomethane obtained from these processes is quite satisfactory, it is important that the future work done in this field should focus on improving the economics of this process and finding the better substrates for this process.

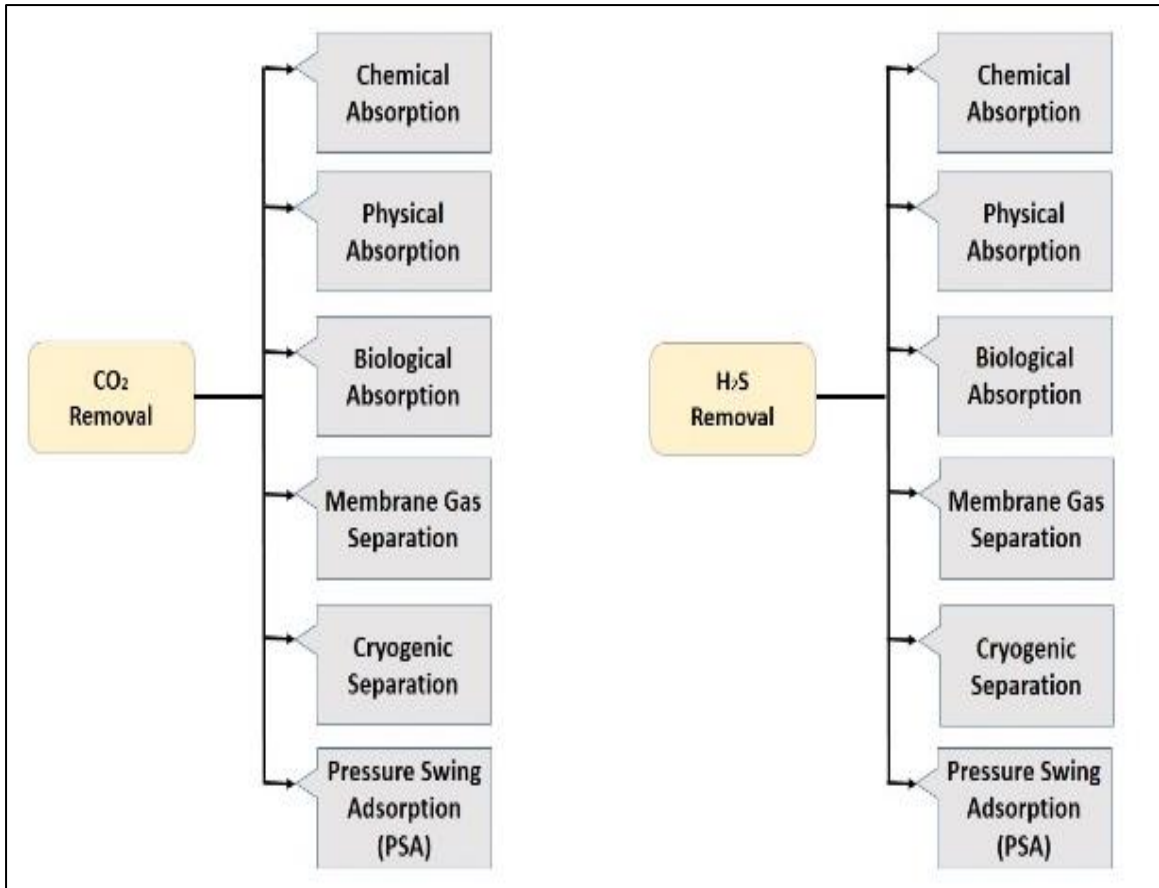


Figure 1: Different methods used for purification of biogas [2]

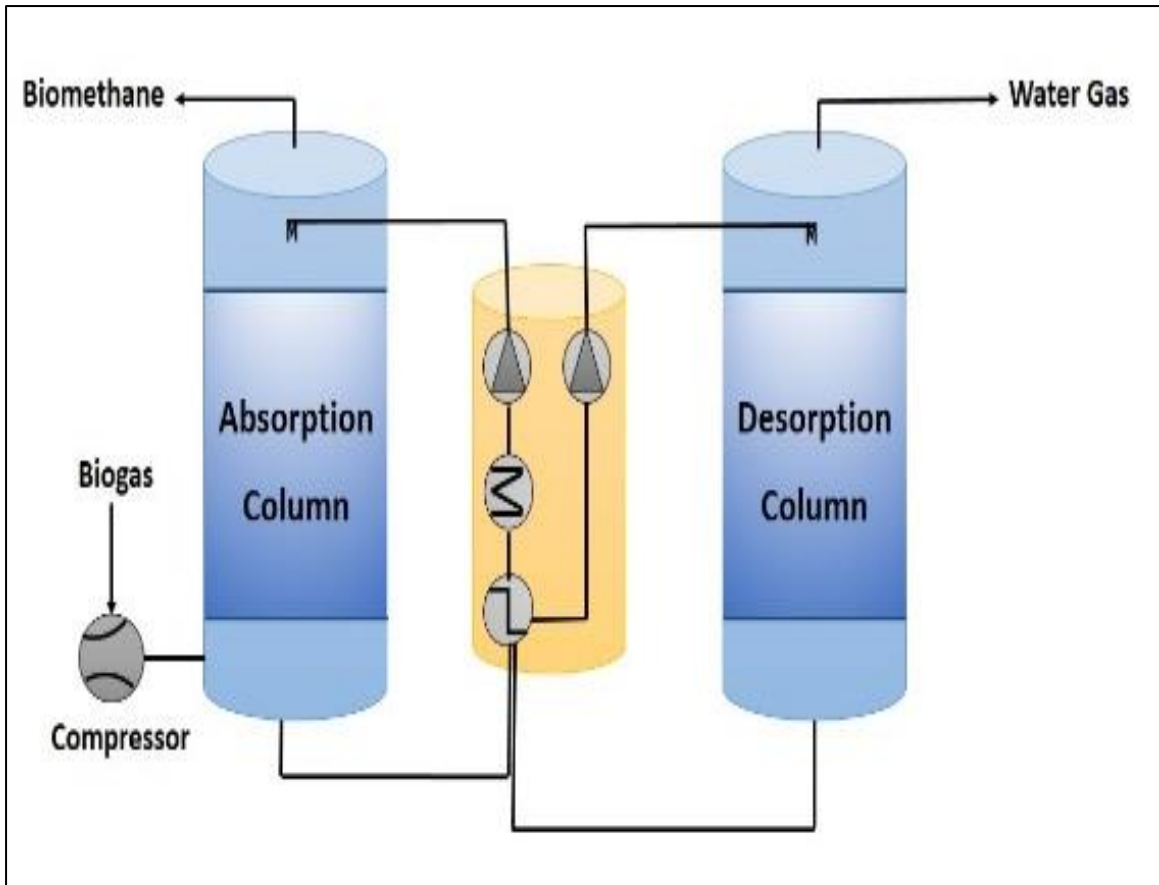


Figure 2: General scheme of biogas purification by water [7]

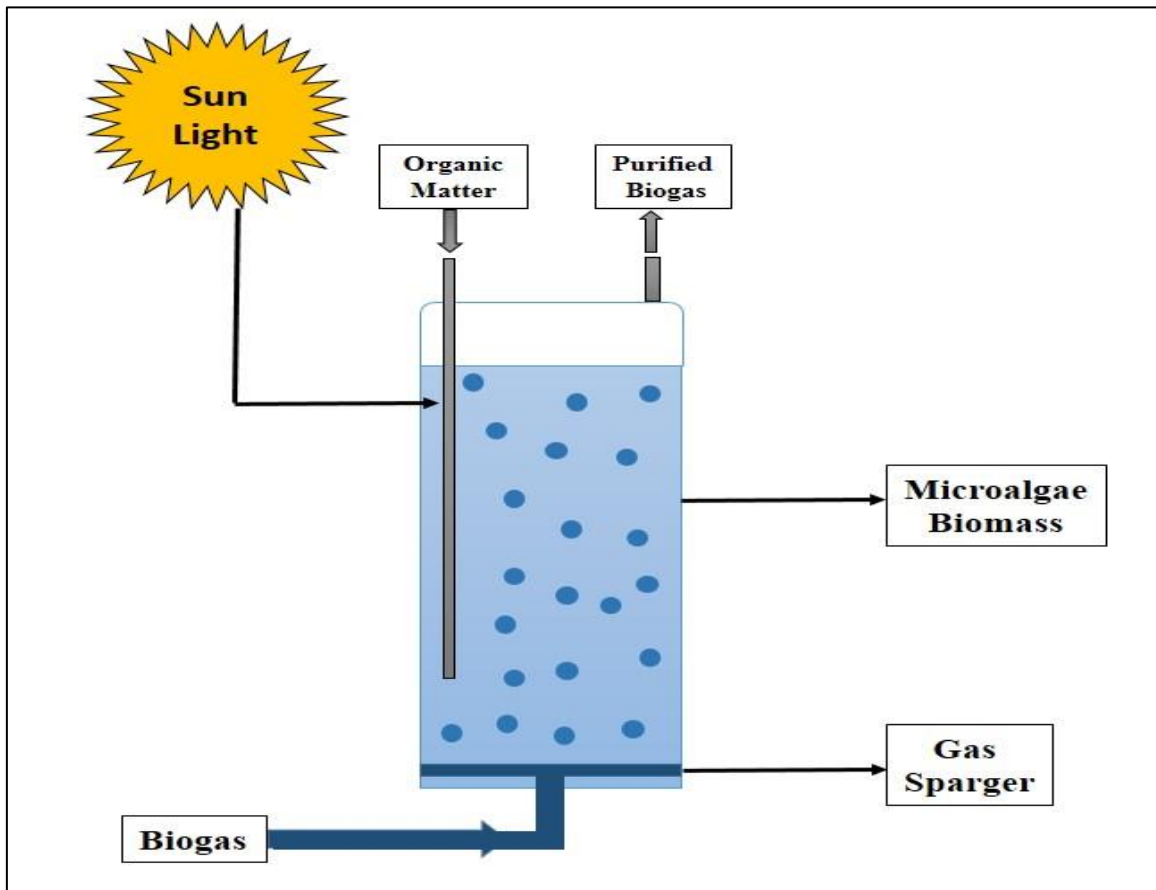


Figure 3: Involvements for microalgae growth [24]

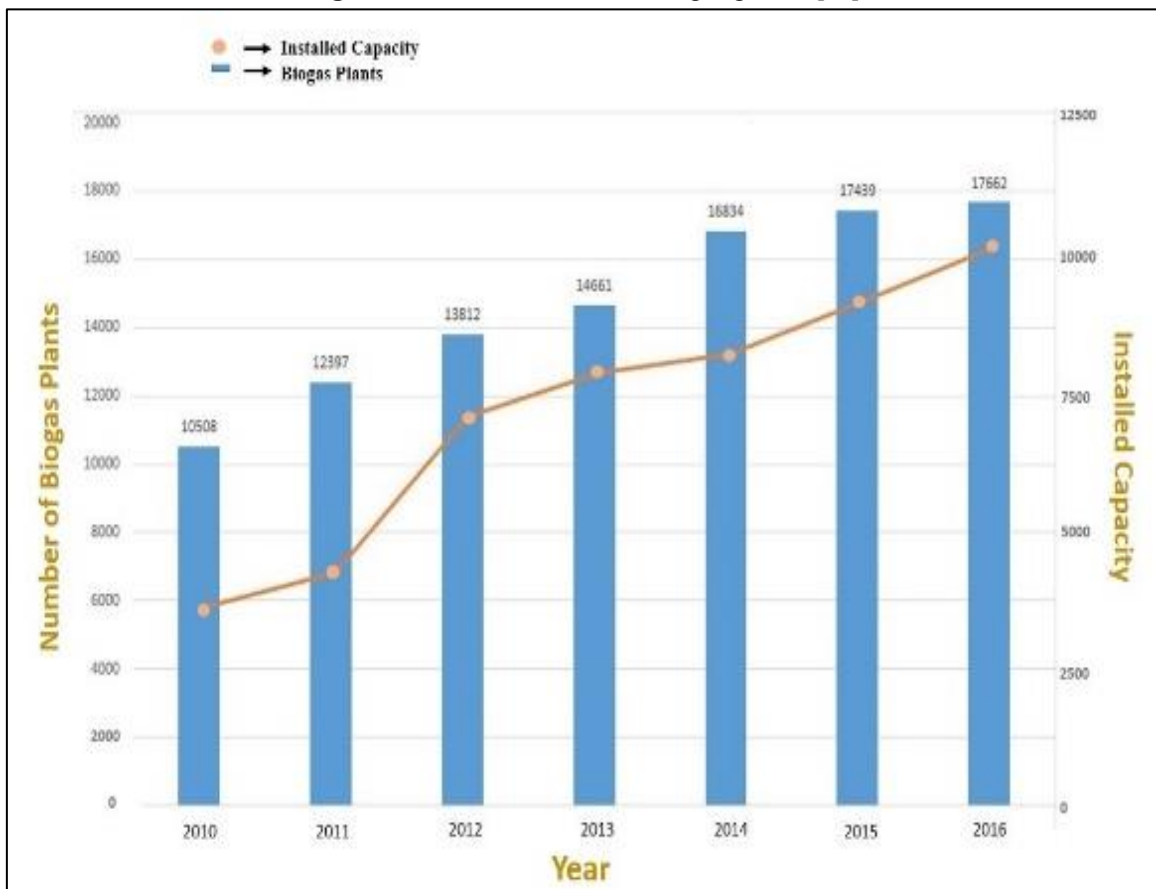


Figure 4: Plot between number of biogas plants VS installed capacity in Europe 2010–2016 [25]

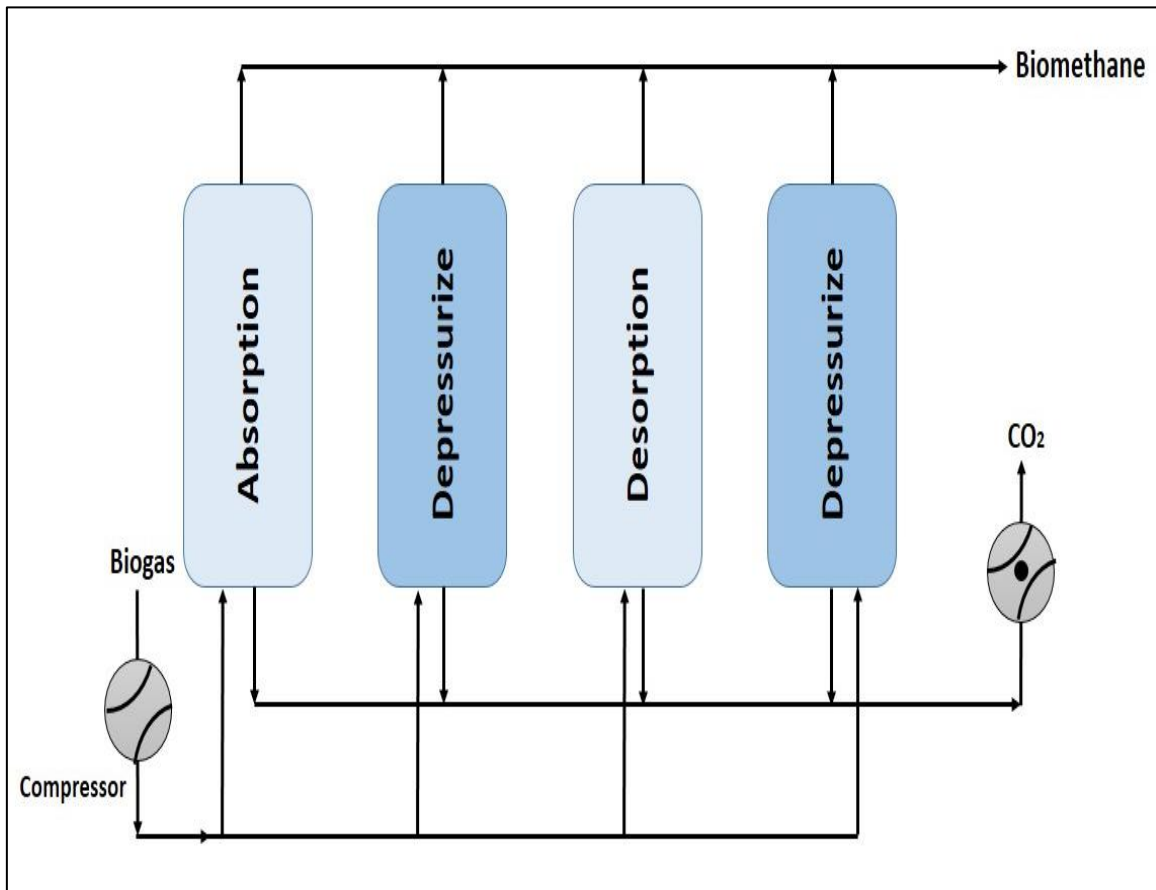


Figure 5: PSA System [14]

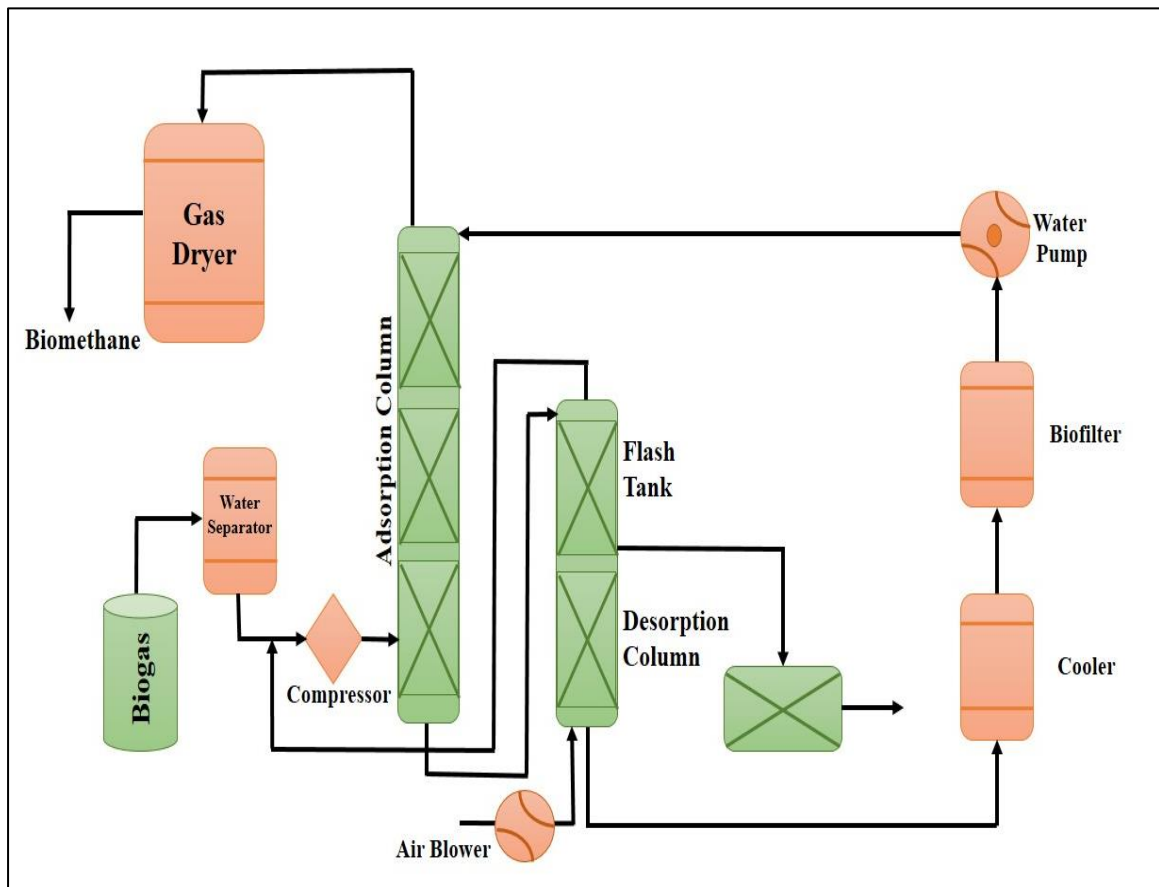


Figure 6: HPWS [16]

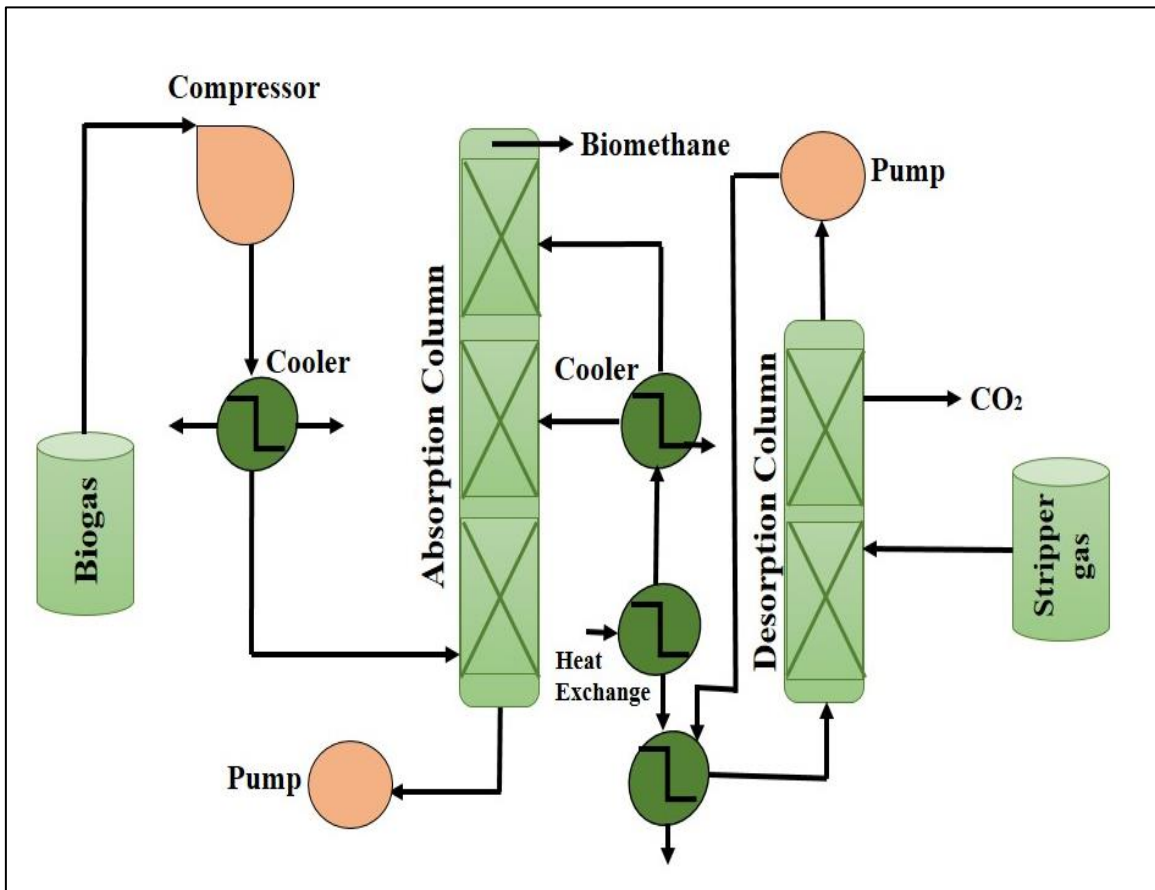


Figure 7: OPS process [26]

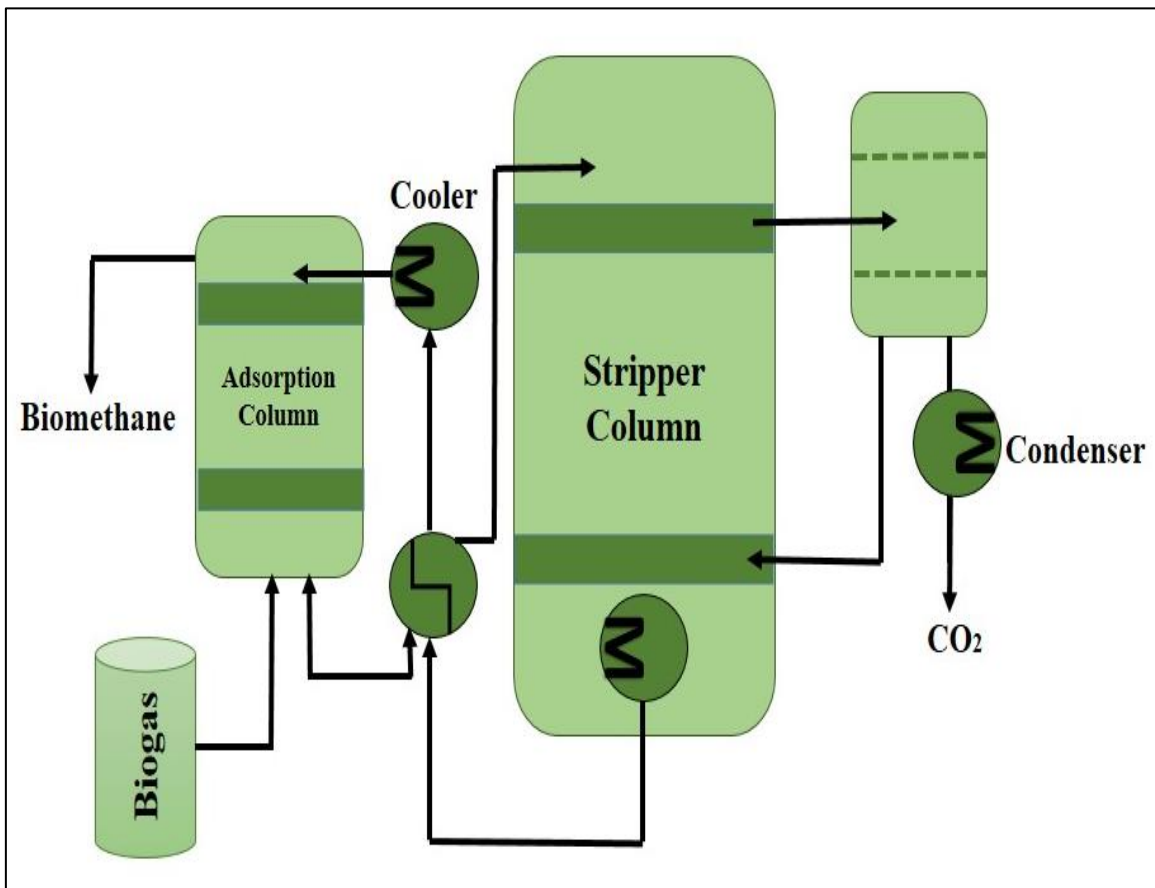


Figure 8: Chemical Scrubbing [27]

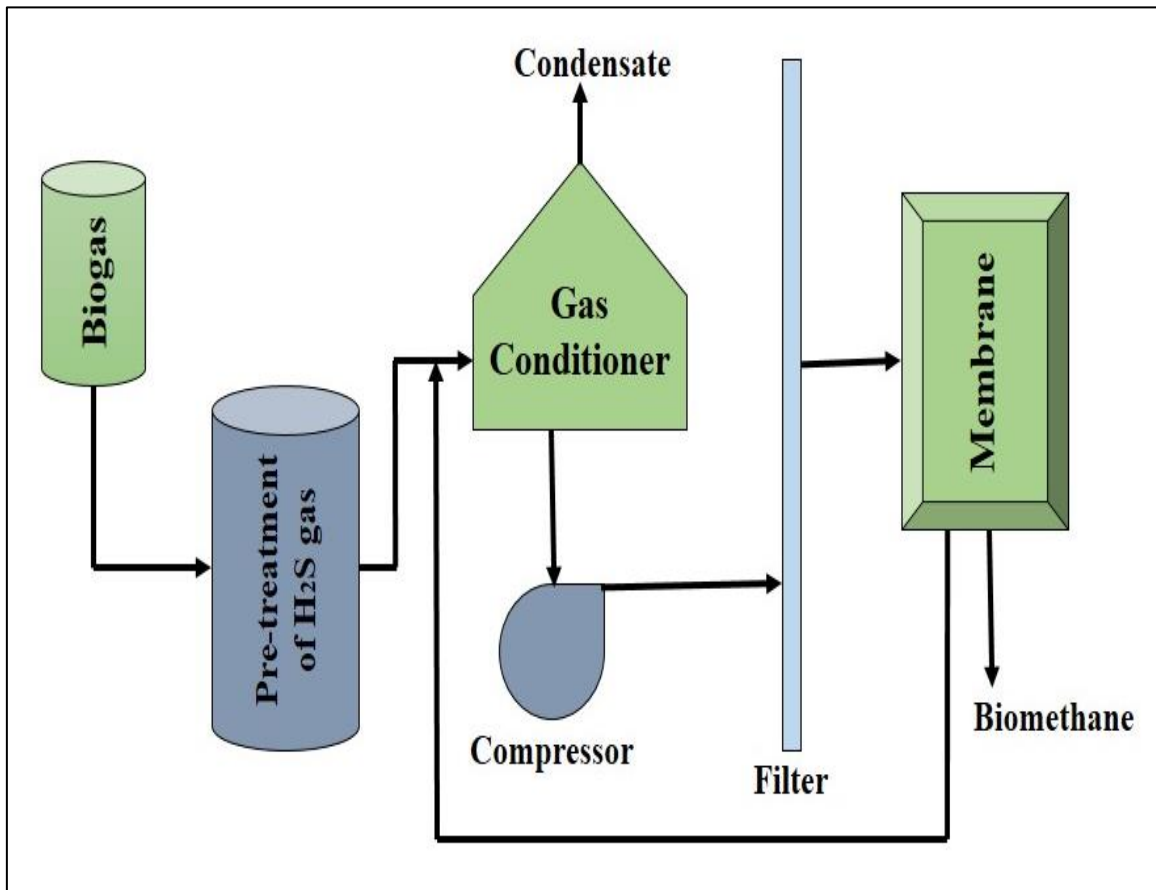


Figure 9: Membrane Separation [15]

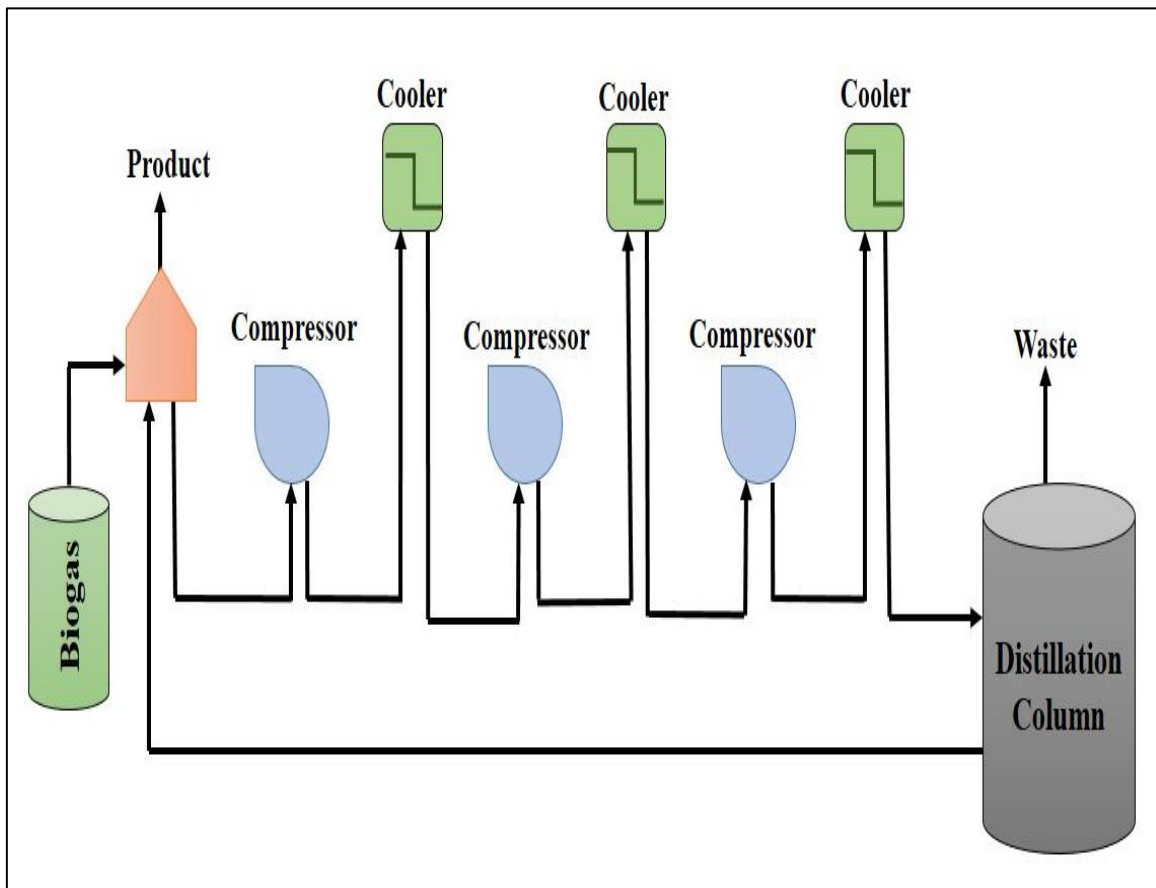


Figure 10: Cryogenic Separation [26]

**Table 1:** Difference of composition between natural gas and biogas

Components	Natural gas	Biogas	References
Methane	80-90 (% vol)	59-71 (% vol)	[14-15]
Hydrocarbons	3-10 (% vol)	-	[15-28]
Carbon dioxide	0.65-1.1 (% vol)	31-41 (% vol)	[15-28]
Nitrogen	0.0-0.20 (% vol)	0.27-14.5 (% vol)	[14]
Hydrogen Sulphide	0.1-4000.5 (ppm)	-	[14-15]
Ammonia	0.1-100.5 (ppm)	-	[14-28]

**Table 2:** Comparison of different reagents used for physical absorption of CO<sub>2</sub>

Reagent	Flow of biogas	Flow of reagent	Temperature in °C	Initial CO <sub>2</sub> conc. (%)	Final CO <sub>2</sub> conc. (%)	Initial CH <sub>4</sub> conc. (%)	Recovered conc. Of CH <sub>4</sub> (%)	Reference
H <sub>2</sub> O	1.5 m <sup>3</sup> h <sup>-1</sup>	1.80 m <sup>3</sup> h <sup>-1</sup>	AT*	40	1	60	85.0	[29]
H <sub>2</sub> O	10.0 bar	15.1 Ls <sup>-1</sup>	10.0	21.1	6.91	45.0	85.0	[30]
H <sub>2</sub> O	25.0 Lmin <sup>-1</sup>	20 Lmin <sup>-1</sup>	26.0	-	-	69.0	93.0	[31]
H <sub>2</sub> O	-	-	AT*	-	8	55-65	75-95	[32]
H <sub>2</sub> O	-	50 Lmin <sup>-1</sup>	AT*	15	11.62	66.6	-	[33]
H <sub>2</sub> O	60 Ls <sup>-1</sup>	0.149 Ls <sup>-1</sup>	AT*	20.2	0.111	51.11	70.5	[34]
H <sub>2</sub> O	1.29-1.81 Lmin <sup>-1</sup>	0.20 Lmin <sup>-1</sup>	AT*	42.72	4.981 L	54.631	90.0	[35]

**Table 3:** Comparison of different reagents used for physical absorption of H<sub>2</sub>S

Reagents	Biogas flow	Reagent flow	Temperature (°C)	Initial H <sub>2</sub> S	Final H <sub>2</sub> S	CH <sub>4</sub> initial (%)	CH <sub>4</sub> recovered (%)	Reference
H <sub>2</sub> O/ activated carbon/sawdust	0.651 m <sup>3</sup> h <sup>-1</sup>	20.01 Lmin <sup>-1</sup>	27.00	8800.1 ppm (0.881%)	10.00 ppm (0.010%)	68.571	93.151	[6]
H <sub>2</sub> O	140 Lmin <sup>-1</sup>	-	AT*	6000 ppm (6%)	2933.3 ppm (0.29%)	-	-	[36]
H <sub>2</sub> O	7.41 Nm <sup>3</sup> h <sup>-1</sup>	5.5-11 Lmin <sup>-1</sup>	20-25	100-166.0 ppm (0.010-0.01660%)	13.21 ppm (0.00131%)	50.81-57.91	90.20	[37]
H <sub>2</sub> O	-	50.01 Lmin <sup>-1</sup>	-	18.40 mgL <sup>-1</sup>	-	66.61	-	[33]

**Table 4:** Comparison of different reagents used for chemical absorption of CO<sub>2</sub>

Reagent	Biogas flow	Reagent flow	Temperature (°C)	Initial CO <sub>2</sub> (%)	Final CO <sub>2</sub> (%)	Initial CH <sub>4</sub> (%)	Biomethane (%)	Reference
Soda lime	1 L min <sup>-1</sup>	5 bar	AT*	-	1.340	41.50	97.7	[8]
Ca(OH) <sub>2</sub>	5 L min <sup>-1</sup>	10 L min <sup>-1</sup>	AT*	39.60	-	51.0	89.30	[38]
NaOH	-	-	AT*	46.0	16.0	52.0	80	[39]
MEA	-	-	AT*	46.0	15.0	52.0	85	[40]

AT\* = Ambient Temperature

**Table 5:** Comparison of different reagents used for chemical absorption of H<sub>2</sub>S

Reagents	Biogas inflow	Initial H <sub>2</sub> S (ppm)	Final H <sub>2</sub> S (ppm)	Removal H <sub>2</sub> S (%)
Charcoal	7.94 m <sup>3</sup> (28 Lmin <sup>-1</sup> )	68.09	1.98	97.08
Bokashi	1.70 m <sup>3</sup> (6 Lmin <sup>-1</sup> )	92.61	3.71	96.01
Iron filings	–	–	250	94.08
Iron shaving	111.6 Lh <sup>-1</sup>	180	9.37	94.79
Iron shaving	111.6 Lh <sup>-1</sup>	180	0.75	99.58
Activated carbon	–	1000	610	39
FeO / activated carbon	–	1000	515	48.5
Commercial activated carbon	–	1000	687.5	31.25
Fe <sub>2</sub> O <sub>3</sub> /H <sub>2</sub> O	–	1500	8	99.46
CaO	7 kPa	370	225	40

**Table 6:** Comparison of different species used for biological absorption of CO<sub>2</sub>

Species	Biogas flow (Lmin <sup>-1</sup> )	Initial CO <sub>2</sub> conc. (%)	Final CO <sub>2</sub> conc. (%)	Initial CH <sub>4</sub> (%)	Final CH <sub>4</sub> (%)
<i>Chlorella vulgaris</i>	0.9	28	8.56	71	91
<i>Chlorella vulgaris</i>	1.8	28	15	71	85
<i>Arthrospira platensis</i>	–	19.5	–	76	–
<i>Chlorella vulgaris</i> (10%w L <sup>-1</sup> )	–	39.6	32.2	60.4	67.6
<i>Chlorella vulgaris</i> (30%w L <sup>-1</sup> )	–	39.6	25.5	60.4	74.5
<i>Chlorella vulgaris</i> (60%w L <sup>-1</sup> )	–	39.6	39	60.4	60.5
<i>Chlorella vulgaris</i> / <i>G. lucidum</i>	–	33.7	23.5	64.59	–

**Table 7:** Comparison of different species used for biological absorption of H<sub>2</sub>S

Bacteria	Genus
Aerobic	<i>Acidianus, Acidithiobacillus, Aquaspirillum, Aquifex, Bacillus, Beggiota, Methylobacterium, Paracoccus Pseudomonas, Starkeya, Sulfolobus, Thermitiobacillus, Thiobacillus y Xanthobacter.</i>
Anaerobic	<i>Allochromatium, Chlorobium, Rhodospseudomonas, Rhodovulum Thiocapsa</i>

**5. Conclusions**

Biogas is generated from the fermentation of organic matter, which consists of gases like CO<sub>2</sub> and H<sub>2</sub>S, making biogas a toxic and pungent gas with corrosive properties. Due to these component gases, biogas cannot be used as raw biogas as a source of fuel, and it needs purification. For the purification of biogas, different methods are used which mainly focus on removal of H<sub>2</sub>S and CO<sub>2</sub>. Water is employed as a natural absorbent in physical processes, however the volume of water required makes this procedure not entirely feasible on a large scale. The most effective methods for eliminating CO<sub>2</sub> and H<sub>2</sub>S (over 90%) have been chemical processes; however, use of diluted chemicals may produce additional residues that need to be treated or neutralized. When it comes to purifying biogas, biological techniques are new and have proven to be more than 90% successful. However, research employing biological techniques has only been carried out in lab settings. When significant CH<sub>4</sub> losses are prohibited, cryogenic technologies have shown to be successful. In terms of various costs, membrane separation plants have the lowest CC, while water scrubbing has the lowest OMC. The structure of the biogas plant must be taken into consideration when determining method of conditioning the raw biogas because certain specifics may be needed. These methods are being used for the purification of biogas and studies in this field are also trying to improve the process day by day in terms of using safe and environment-friendly

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substrates and making the process with less cost. The use of purified biogas helps in reducing pollution, toxicity, and emission of greenhouse gases caused by use of raw biogas.

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